SNS 109020000-SR0001-R00

Spallation Neutron Source

Systems Requirements Document for Timing System

January 2000

Draft Feb 23, 2000

A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Lawrence Berkeley National Laboratory • Los Alamos Naitonal Laboratory • Oak Ridge National Laboratory

SNS

SNS 109020000-SR0001-R00

SPALLATION NEUTRON SOURCE
SYSTEMS REQUIREMENTS DOCUMENT
FOR TIMING SYSTEM

Date Published: January 2000

Prepared for the
U.S. Department of Energy
Office of Science

LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
managing the
Spallation Neutron Source Activities at the
Argonne National Laboratory
Brookhaven National Laboratory Lawrence Berkeley National Laboratory
Los Alamos National Laboratory Oak Ridge National Laboratory
under contract DE-AC05-96OR22464
for the
U.S. DEPARTMENT OF ENERGY

SNS 109020000-SR0001-R00

SPALLATION NEUTRON SOURCE
SYSTEMS REQUIREMENTS DOCUMENT
FOR TIMING SYSTEM

January 2000

D. Gurd **Controls Systems Senior Team Leader**	**Date**
R. Kustom **Accelerator Division Director**	**Date**
T. E. Mason **Experimental Facilities Division Director**	**Date**
L. E. Temple **SNS Project Director**	**Date**

CONTENTS

1. PURPOSE

A modern physics facility must synchronize the operations of equipment over a wide area. The primary purpose of the sitewide SNS synchronization and timing system is to synchronize the extraction of the accumulator ring to the Fermi neutron choppers and distribute appropriate timing signals to various accelerator systems, including the Injector, the Linac, and the Accumulator Ring. Signals to be distributed by the system include the ring RF clock, real time timing triggers, machine mode and other informational events. Timing triggers and clocks from the SNS synchronization and timing system are used to synchronize hardware operations including the LINAC beam chopper, equipment state changes, and data acquisition for power supplies and beam diagnostics equipment.

2. SCOPE

The timing system to be developed under WBS 1.9.2.2 is comprised of a phase locked loop (PLL) to generate a 600 Hz power line locked clock, a master timing system including VME chassis, input modules, timing system encoder, distribution system to all equipment locations, and a general purpose VME receiver module. The VME receiver module shall be configurable to respond to user selectable timing events and provide TTL electrical pulse outputs and local delay capability. Receivers will be provided for all equipment requiring access to timing system signals. Chassis to house the receiver modules are not included. This document is written for a linac operating at 1.0 GeV and an accumulator ring of 248 meters. There will be no design changes necessary if the Linac energy is increased to 1.3 GeV.

3. REQUIRMENTS

3.1 NEUTRON CHOPPER TO AC-LINE SYNCHRONIZATION

The neutron choppers are very high inertia mechanical rotors with collimators that chop the neutron beam, rotating at a high harmonic of the line frequency, probably (but not always) at 600 Hz. There are several such choppers, but one will be used as the reference for the others. The frequency and phase of the neutron chopper will be phase locked to a line reference ("line-sync") signal, which in turn is phase locked to the ac line zero crossing. The desired timing accuracy for the synchronization of the neutron chopper to the line-sync signal is about ±0.5µs. The required accuracy is still to be determined, but is in the ±1 µs range.

The ac-line synchronization requirement is to maintain a timing accuracy of about ±100 µs or better between the zero crossing and the line-sync signal, even during line frequency transients and diurnal variations. This requirement stems from the need to synchronize the linac klystron modulators pulses to the ac line zero crossing in order to have pulse to pulse repeatability in the klystron performance.

In order to synchronize the accelerator systems to the neutron chopper PLL, a phase-stable timing signal, is generated and distributed around the facility. This 600 Hz signal shall be used to generate several key timing signals (events) on the beam-sync timing system. The specific reason for this frequency choice will be discussed later.

3.2 SYNCHRONIZATION OF RING EXTRACTION TO NEUTRON CHOPPER

The beam occupies about 67% of the ring circumference, and the remainder of the ring (the beam gap) is free of beam (to about 1 part in $l0^5$) in order to accommodate "clean" extraction (without unnecessary beam loss). The extraction from the ring must be synchronized to the beam to about ± 5 ns (the beam gap is about 280 ns long). Because the synchronization requirement for the ring extraction to the neutron chopper is longer than 1 ring revolution period, the phase of the beam in the ring does not need to be synchronized to the neutron chopper prior to extraction. The neutron chopper system shall provide an l000 ns gate signal during which the ring extraction kicker is triggered when the beam gap at the correct azimuth. **The circuitry for generating the l000-ns gate, and synchronizing the neutron choppers to it, is the responsibility of the group developing the neutron choppers**.

3.3 SYNCHRONIZATION OF LINAC

In order to inject approximately 1160 turns into the ring, the beam injection into the linac must begin about 1096 µs before extraction. For a normal-conducting linac, the klystron modulators must be pulsed about 100 µs earlier than the beam The reason for this is to fill the if cavities with field before the injection of beam. Thus the first required timing pulse for a complete beam pulse cycle is required about 1500 µs before the ring extraction time.

When the ring is full at the end of accumulation, the beam must be extracted as quickly as possible, say <10 µs, after the last turn is injected to avoid beam growth. If the accelerator cycle timing start signal T_0 is based on 60-Hz line-sync signal, which has a period of 16,667 ± 50 µs (due to line frequency variations), the variation in the delay between the cycle start signal T_0 and the extraction time exceeds the allowed storage time in the ring. By using the l0th harmonic of the line frequency, 600 Hz (which has a period of 1667 ± 5 µs) as the source for T_0, the critical systems in the linac (modulators, injector, etc) can be triggered with a timing error not exceeding the allowed 10 µs "window" relative to the extraction time. This will be shown in Fig. 2.

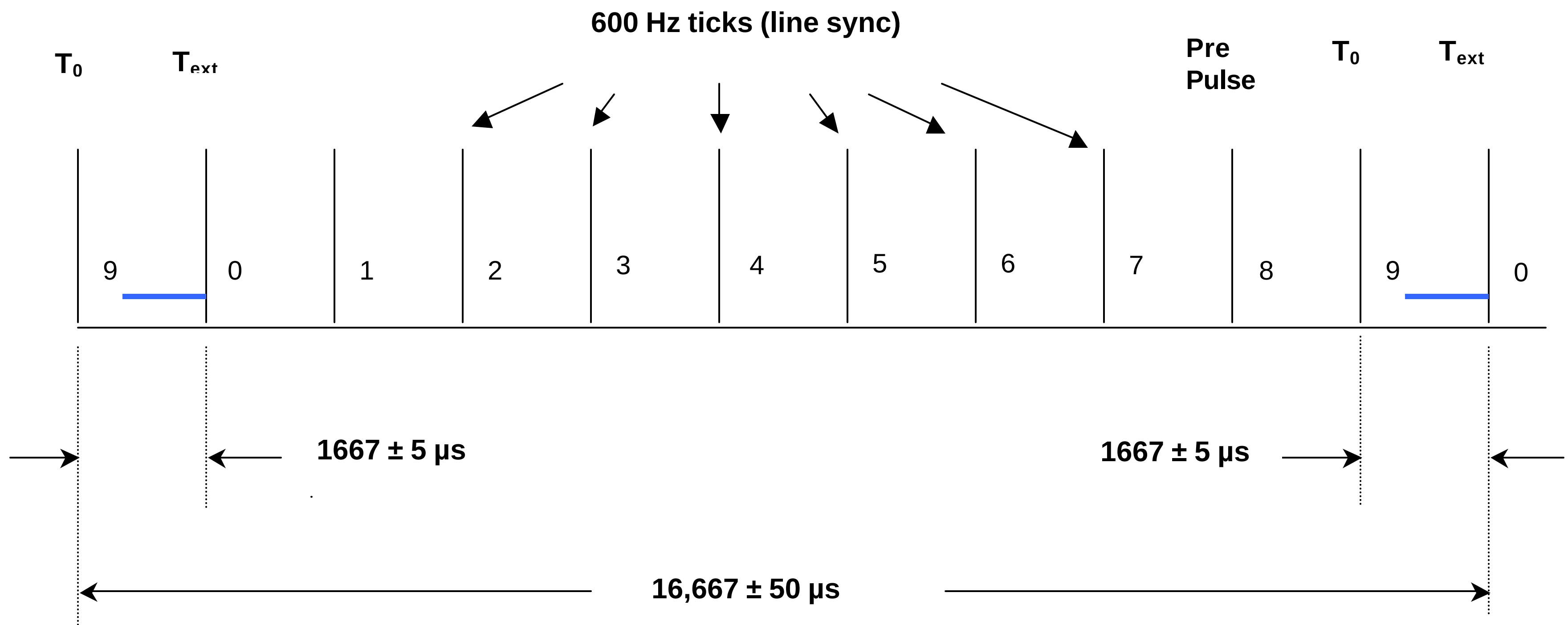

Figure 1: Typical 60 Hz line cycle

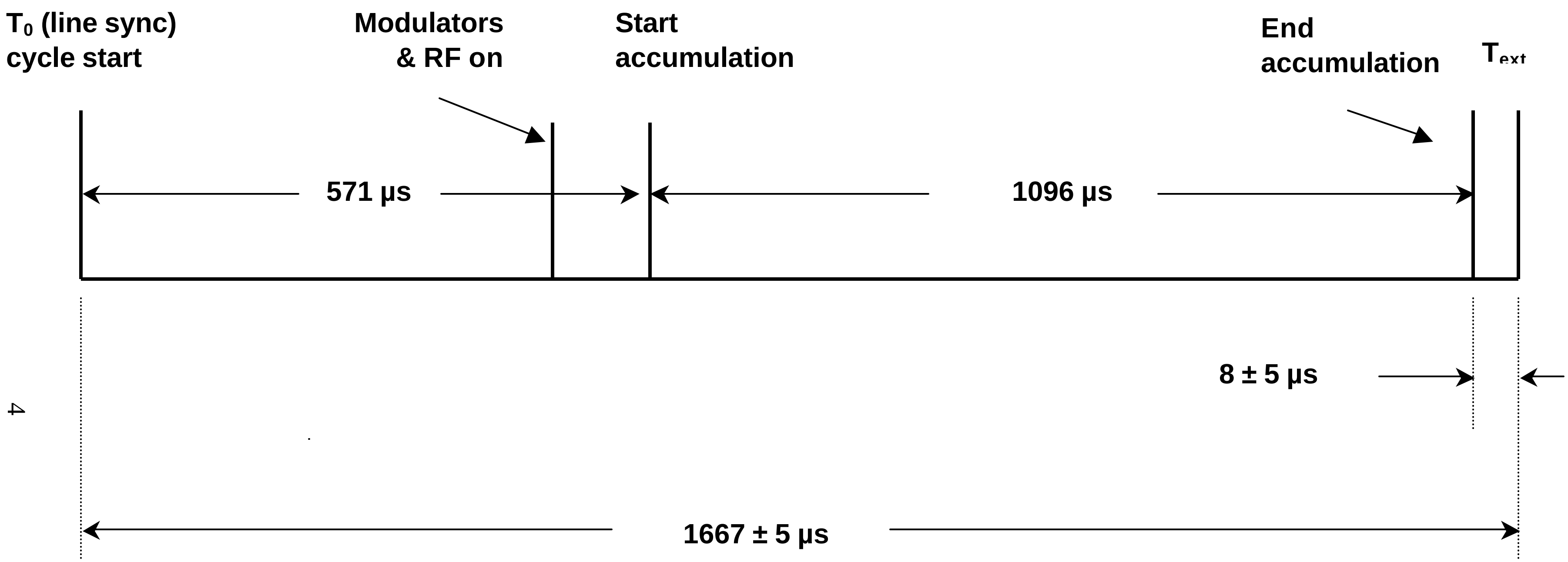

Figure 2: Detail of Accumulation Cycle

3.4 VARIATION IN THE RING REVOLUTION PERIOD

For a 1 GeV proton circulating in a ring of circumference 248 meters, the revolution period is 945.4 ns. During normal operation, tuning the ring by changing the B field (which changes the orbit radius), or tuning the linac to change the injection energy, or a combination of both, can change the revolution period by up to ± 2 ns. During ring commissioning, the change can in principle be even larger. Although 2 ns is not a large number, the cumulative timing error over a normal accumulation cycle of 1200 turns exceeds 2 µs, more than one complete ring period. This is much larger than the desired cumulative synchronization accuracy of ± 5 ns for accumulating 1200 turns of beam in the ring. Any cumulative error exceeding 10 ns can begin to fill in the beam gap in the ring. Any beam in the gap will activate the extraction septum.

Figure 1 shows the overall 16.667 ms timing cycle for beam accumulation in the ring. Figure 2 shows a detail of the 1.667 ms period beginning with the cycle T_0 pulse. The T_0 pulse is every 10^{th} tick of the 600-Hz line-sync signal. In both Fig. 2 and 3, T_{ext} (ring extraction time) is one 600-Hz period later. This should be synchronous with the 1000 ns gate from the neutron chopper PLL.

3.5 LINAC BEAM CHOPPER SYNCHRONIZATION

The beam in the linac injector is chopped by two systems, a gated electrostatic focusing electrode in the LEBT, and a traveling-wave deflector (beam chopper) in the MEBT following the RFQ. Each of these systems, and especially the beam chopper in the MEBT, must be synchronized to the ring period. The reason for chopping the beam is to produce a gap in the beam current, that is synchronized to the ring period with a cumulative error of about ± 5 ns for the entire 1200 µs accumulation period.

3.6 BEAM DIAGNOSTICS SYNCHRONIZATION

3.6.1 Ring Diagnostics

The beam diagnostics in the ring measures the revolution of the beam during the accumulation cycle. The ring beam diagnostics measurements include global systems such as beam closed orbit measurement (BPM) system, and local systems such as the azimuthal distribution of beam charge density (current monitor). Global and local refer respectively to systems that are widely distributed around the ring, or are needed in only one or two azimuthal locations. These systems need to be synchronized to the beam in the ring to within about ±5 ns, even though the accumulation period may vary by 1200 ns or more.

3.6.2 Linac Diagnostics

Although the linac RF is not synchronized to the ring, the periodic beam gap in the linac is. Because of the effect of the beam gap on the performance of the linac beam diagnostics, the sampling of the beam diagnostics signals from all the diagnostics needs to be synchronized relative to the beam gap. In particular, beam current, beam position, and beam synchronous phase measurements would benefit from being synchronized relative to the beam gap. Thus the linac diagnostics also needs to be synchronized to the beam in the ring. A 60-ns timing granularity (not jitter) of a timing signal relative to the beam gap is adequate (the beam gap is 280 ns long, and the beam mini pulse between beam gaps is 560 ns long).

3.6.3 Beam lines

Diagnostics in the beam line between the linac and ring requires synchronization to the ring period. In addition, RF cavities in this beam line require the 805-MHz reference signal. Diagnostics in the beam line between the ring and the spallation target need only a single pretrigger a few 100 ns before extraction.

4. SNS TIMING SYSTEM

The most convenient way to *broadcast* timing signals to many hundreds of clients distributed over a kilometer or more of accelerator and beam lines is to encode all the timing signals on a carrier frequency (clock), and to distribute this signal to all clients. Encoding the timing signals on the same cable (or fiber) as the clock eliminates the possible timing ambiguity due to non-equal cable lengths. If the carrier frequency on which the events are encoded, is synchronous with the beam in the ring, rather than a fixed frequency, then timing triggers and delays derived from the carrier frequency maintain the proper relationship with the beam revolution period. This eliminates the need to adjust timing delays due to changes in the ring revolution period, even though the total ring accumulation period may vary by as much as ±2 µs.

Each receiver decodes the timing signals and recovers the carrier (clock) frequency. Digital filters in each receiver are configured to recognize specific real-time trigger signals, which are synchronous with the clock cycles. Output signal levels for clock and trigger outputs from the general purpose decoder delay module shall be TTL signal levels with 50 Ù drive capability.

An SNS timing and synchronization workshop, held at Brookhaven National Laboratory on May 3-5, 1999 concluded that the beam synchronous timing system developed for Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) could serve as a model for the SNS synchronization and timing system. The RHIC beam synchronous timing system is comprised of three subsystems, a central delay generation and encoding facility, a fiber optic and copper cable distribution system and a general purpose VME decoder/delay module (receiver). Adapting the RHIC system for SNS reduces the development time and takes advantage of proven technology reducing the engineering risk. Modifications to the RHIC system to meet SNS needs would be minor.

The SNS accumulator ring revolution period is ~1.05 MHz for a 248 meter ring operation at 1GeV. If we operate the SNS timing system on a carrier frequency exactly 16 times the ring revolution frequency, from a clock supplied by the ring low level RF, the carrier frequency will be ~16.92 MHz. Choosing a carrier frequency 16 times the revolution period of the ring allows easy recovery of the 1.05 MHz revolution clock at the receivers. Experience from the RHIC beam synchronous timing system shows that short term jitter due to encoding, signal distribution and clock recovery can be kept below 2 ns. Drift due to thermal effects of the fiber are 38 ps/km/ºC.

Based on the requirements outlined above, the specification of the SNS timing and synchronization system is described below.

Timing stability

About ± 5 ns (relative to the beam in the ring). This includes long-term drift and pulse-to-pulse jitter. Stability in this range allows use of the timing system for triggering the beam chopper in the linac injector and the extraction kicker in the ring, as well as for all the beam diagnostics. The timing system described here does not need to address the timing (phase) stability of the linac if systems, which must be stable to ±0.5 degrees at 805 MHz (about ± 0.002 ns).

Frequency compliance (to variations in ring revolution frequency)—Many systems in the injector, linac, and ring, will have individual downloaded delay settings (integer cycles of a reference clock). Variations of the ring revolution period up to ± 2 ns (± 2400 ns for a complete accumulation period) should not require changing any downloaded preset delay settings in order to maintain the 5 ns timing stability relative to the beam in the ring.

Clock—The distributed clock signal must be CW, independent of whether beam is in the ring.

Real-time event encoding—The SNS timing encoder shall have the ability to encode and transmit 100's of distinct timing signals ("events") in a real-time fashion (meaning synchronized to a clock). An event prioritizing system is provided to ensure that important timing signals are transmitted on the correct clock cycle. Real-time events include all the preset timing signals, such as for beam choppers, klystron modulators, etc. In addition, triggers are required for synchronizing beam diagnostics measurements (beam position and beam synchronous phase measurements in the linac, closed orbit measurement in the ring, and pretriggers are required for the diagnostics in the ring-to-target beamline).

Number of distinct event (trigger) types—The SNS timing system shall be capable of transmitting 256 different timing signals.

Granularity—This refers to the timing system clock period, which should be short relative to the ring period. This relates to the minimum step size in setting the transmission time of encoded events. Granularity for a 16.92 MHz carrier is 59 ns. Finer delay settings can be achieved by using fixed length cables, or by using delay chips that are remotely programmable with better than 5-ns delay granularity and stability. *Granularity* does not need to be as good as *timing stability* (see above).

Transmission method—Broadcast transmission over optical fibers or cables using a self-clocking encoding scheme in which the timing signals are encoded on the clock signal. The receivers each recover the original unmodulated clock signal (carrier), and have individually programmed digital filters to recognize and decode specific encoded timing "events".

Distribution mechanism—Encoded event (trigger) signals and clock are distributed the on same fiber (or cable) to permit convenient distribution over the entire site. The SNS timing system is distributed via singlemode fiber-optic cable to all equipment buildings where a fiber optic receiver converts it to an electrical signal. Distribution within an area is point to point on twisted pair copper cable.

Distribution area—Sitewide. Preference was shown at the BNL workshop for a single sitewide timing system rather than several local systems; e.g., one for the ring and another for the linac. This means that *all* receivers will receive *all* transmitted events, including linac-specific and ring-specific events.

Bit error rate (BER)—Whatever it has to be to ensure an acceptable reliability.

Informational events—The timing system should have the ability to distribute *informational* events as well as *timing* events. *Informational* events might include identifying the accelerator cycle type (e. g., beam to spallation target or to linac beam dump, or Beam Pulse Disable (e.g., ring extraction kicker capacitor bank not completely charged by time T_0). The critical timing signals occur in the 1.67 ms between T_0 and $T_{ext.}$

(see Fig. 3). There is 15 ms between T_{ext} and the next T_0 signal, and about 600 µs after To for informational events. Informational events can be transmitted with a lower priority that (can be "bumped" by) timing events because their exact timing is not critical.

Priority system for event transmission—Critical timing events are given priority for a given time slot to prevent any contention. Non-critical timing signals are delayed (by about I µs (a 12-bit word requires about 12 clock cycles or 630 ns to transmit). Informational events have a low (low-time-critical) priority.

Time stamp—This timing system is not intended to replace the need for the normal time stamp requirement. The time stamp must be accurate enough to uniquely identify individual 60-Hz beam pulses. The function of the timing system is to synchronize systems to a few ns within individual beam pulses.